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CARTOGRAPHIC DATA RETRIEVAL, ANALYSIS, DEPICTION, PRESENTATION AND PRODUCT GENERATION: DIGITAL DATA BASES

The digital chart of the world project

Paper submitted by the United States of America**

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The Defense Mapping Agency is developing a new product, The Digital Chart of the World. It will provide world wide coverage using a topologically structured vector representation of the earth's land surface information on a micro-computer accessible storage medium. The ultimate objective of this project is to develop, refine and establish a suite of standards to support future Defense Mapping Agency digital data production and enhance the utility of digital spatial information in vector format. The Digital Chart of the World database will be used to test and define product standards; once the standards are complete the Digital Chart of the World will provide an example for future Defense Mapping Agency products.

The standards and the Digital Chart of the World product are being developed in cooperation with the United Kingdom, Canada, and Australia. International participants will review draft standards and specifications; exercise and evaluate prototypes; assist in the design of user pathways into the data; and develop hardware and software utilities to send, receive and exploit the data.

Introduction

The Digital Chart of the World Research and Development project, initiated in 1988, has as its primary goal the development of Vector Product Standards for the provision of digital geographic information to U.S. Department of Defense and Intelligence Community activities.

As a secondary goal the project will develop the product specifications for a 1:1,000,000 vector map database. Over 275 Operational Navigation and Jet Navigation Charts will be digitized to provide a product with worldwide coverage. The new product, the Digital Chart of the World, will contain several gigabytes of topologically based vector data.

Environmental Systems Research Institute of Redlands, California is the prime contractor for the project. The project is a multinational effort. The development partners are the United States, Canada, Australia, and the United Kingdom. The military map producers from these four nations, the primary producers of the Operational Navigation Chart Series which will provide the information for the Digital Chart of the World, have joined in this effort to establish standards for data structures that will support direct use in geographic information systems, CRT displays, and special computer environments. The Digital Chart of the World will be the first product generated according to these standards. This paper discusses the process followed for accomplishing the project goals of Standards Development and Product Development.

STANDARDS DEVELOPMENT

Background

Increasing Demands for Digital Data Although the demands for Defense Mapping Agency's conventional paper products are as high as ever, the demand for video and digital data is increasing. There has been a significant increase in the number of automated systems supporting military functions. Some are captive or special purpose developments, some employ commercial off-the-shelf geographic information systems technology; all require machine readable mapping and charting data. Defense Mapping Agency currently produces video products and digital products which use a raster model (ARC Digitized Raster Graphics), but there is a need for "smart" vector data for selective display and geographic modeling and analysis. To support these functions, the data sets must carry topological relationships and be fully attributed.

Increasing Availability of Digital Data. The Defense Mapping Agency production process is undergoing a modernization program; an end to end Digital Production System will be phased in over the next 5 years. Foreign military mapping agencies are increasing their output of digital data; the nations participating in the Digital Chart of the World project are also extending their production systems to produce more digital data. The digital data pool is also being filled by scanning and digitization efforts in the private sector.

Demand for a "User Oriented" Structure. Presently there is a variety of structures and standards for digital vector data. Available non-commercial data transfer structures include:

TIGER - Topologically Integrated Geographic Encoding and Referencing files, Bureau of the Census.

DLG-E - Digital Line Graph Enhanced, US Geological Survey.

SDTS - Spatial Data Transfer Specification, Federal Geographic Data Committee.

DIGEST - Digital Geographic Information Exchange Standards, Digital Geographic Information Working Group, (an ad-hoc group of NATO nations).

MC&GFDES - Mapping, Charting, and Geodesy Feature Data Exchange Structure, Defense Mapping Agency's Digital Production System.

All of the referenced standards were designed to accommodate producer exchange of data, not user exchange. They support specific implementations rather than a general purpose; apply to bulk transfer of data, with built-in overhead and redundancy; have no requirement for communication between parties; and lack application software. In general, these standards do not support customer requirements for interactive use, tiling, indexing, and manipulation of the data.

With the projected increase in both the generation of digital data, and the number of applications for the data, the need for digital product generation and user exchange standards became evident, and motivated this research and development effort.

Approach

In October 1989 Environmental Systems Research Institute was contracted by Defense Mapping Agency to develop the Vector Product Standards and the Digital Chart of the World. The Vector Product Standards is designed to provide direct database utility and be

oriented to provide Defense Mapping Agency products for use in commercial geographic information systems.

Given enough time any group of engineers can come up with a standard. The quest here is to establish standards that can be readily embraced by the customer community. To accomplish this, two things are required: (1) well designed, standards that support a wide range of user demands and (2) a wealth of data produced according to the standards, to attract the users and promulgate the standards.

To meet this primary goal Environmental Systems Research Institute was required to develop a comprehensive suite of vector product standards. To insure that these standards would fulfill a broad range of needs, be as generic as possible, and work in a wide range of computing environments (both product and platform); the following design constraints were imposed:

(1) The standards must be designed to work within the constraints of a microcomputer (IBM 80286) with a limited amount of hard disk storage (30 MB). This would allow the use of vector products with inexpensive, and in many cases portable equipment. With the exception of tile size any design slated for PC class environment will also operate in workstation and larger environments with increased efficiency.

(2) The standards must be designed for data distribution on Computer Disc-Read Only Memory (CD-ROM). This medium was selected for distribution because it is cost effective, efficient, and operates under established media standards.

(3) The standards must support interactive use of the media, so small computers can use the medium as "on-line" storage.

(4) The standards must be user oriented. They must support geographic modeling and analysis and graphics display. They must be useable by individuals oriented toward geographic information not computer science. The database access software will be available to users of data stored in the Vector Product Standards, and the source code will be available without restriction.

(5) The standards must be designed to work in a variety of computing environments regardless of manufacturer. They must work with a variety of vector data types regardless of the scale of the information or level of topological information.

(6) The standards must be compatible with Defense Mapping Agency's Digital Production System.

Prototyping. In order to insure that the standards would be user oriented and meet user requirements, an incremental, iterative prototyping approach was employed. With each prototype,

increasing quantities of data from several Operational Navigation Charts, hydrographic charts, and a topographic map were digitized and converted to a trial data structure and delivered to over 60 review sites. Review participants included the international development partners and a cross section of Defense Mapping Agency product users from the U.S. Department of Defense and Intelligence communities. A variety of product types were included in the prototypes to ensure that the standards apply to a range of geographic information systems applications at varying scales.

The first prototype, actually an ARC/INFO "mock-up" of the Digital Chart of the World, was delivered to the evaluation team in December 1989. This prototype consisted of a small section of Operational Navigation Chart G-18 (Santa Barbara, California) and a small patch of British Admiralty Chart 2693 (Harwich, England) The evaluators were provided with PC ARC/INFO software, an evaluation guide, hardcopy plots of the database, and complete instructions. By performing feature queries, viewing the data on the screen, and using a mock-up of the Digital Chart of the World software, the evaluators were able to assess the capabilities they wanted the application software to provide. Armed with this information the applications software programmers were able to quickly develop the software for Prototype 2, which was released in April 1989.

Prototype 2 used original "C" code and provided a newly implemented data structure. The data consisted of an expanded area of the two previous charts and also included National Ocean Service Charts 12245 and 12222 (Norfolk, Virginia) and a section of a 1:50,000 topographic map (Killeen, Texas). This prototype, which used 5 floppy disks to carry the data and one to store the software, provided evaluators with a good vehicle to analyze the database design and the new application software.

Prototype 3, released in early August, was the first prototype to use CD-ROM. The sources for prototype 3 were:

Operational Navigation Chart G-18 (California)
Operational Navigation Chart N-13 (Northern Australia)
Operational Navigation Chart E-18 (Ontario-Quebec, Canada)
BA 2(,2 (Harwich, England)
National Ocean Service 12245 (Chesapeake Bay, U.S.)
Jet Navigation Chart 120 (Antarctica)

The application software was supplied on a separate floppy disk. This was the first prototype on the target medium and the first to implement the Vector Product Standards. The objectives of this prototype were two fold. First, to provide the standards, the software, and the data to the evaluation team; and secondly, to provide a test bed for the organization of the data, directories, and indices on CD-ROM. Along with the basic prototype sets Environmental Systems Research Institute added 8 test sets. These sets, with various structures of indices and directories, were

used to test data organization directly, with the CD-ROM in various drives. The sets provided calibration data for off-line tests to determine the optimum methods for storing this information. This will allow the Digital Chart of the World and other products to optimize the slow seek time and fast read time of the CD-ROM medium.

Recommendations from prototype 3 were then tested in prototype 4. Prototype 4 tested both the data structures and the production process. Using four Operational Navigation Charts from western Europe, E-01 (UK), F-01 (France, N. Spain), G-01 (S. Spain, N. Africa), and G-02 (N. Africa, S. Italy), prototype 4 tested the digitizing, feature tagging, transformation into the product format, indices and directories, CD-ROM production, and quality control throughout the process. This prototype and its specification constitute the first sample of the future Digital Chart of the World product.

This method of prototyping worked very well. Engineering ideas were quickly tested; the designs that didn't work well were quickly discovered and discarded, saving months of study and debate. Sound ideas were expanded and further proven with each iteration.

Studies.

A number of special studies have been initiated by Environmental Systems Research Institute to support prototype development. The Vector Product Standards has been separated into protocols, and Environmental Systems Research Institute has conducted research investigations into the various elements comprising each protocol. The lowest level protocols, those for CD-ROM, are following existing ISO 9660 standards and are not studied. The mid-level protocols consist of the spatial data structure, feature identification codes, and product content rules; at this level the studies include the Data Storage Structure Study, the Data Dictionary Study, the Digitizing Convention Study, the Aeronautical Study, and Elevation Data Study. The high level protocols consist of the data directory protocols; at this level the studies include the Tile Design Study, and the Indexing Studies: Coverage, Thematic, Gazetteer, and Spatial Query.

These studies were conducted in an iterative manner. Environmental Systems Research Institute initiated each study by investigating user needs, then conducted literature searches, consulted with area specialists, and issued a preliminary study which was sent to appropriate development participants for comment and enhancement. Responses were consolidated and used by Defense Mapping Agency to direct the contractor in refinement of the studies. The study findings were then folded into the prototypes for testing. The study delivery dates were staggered, each timed to mature coincident with the integration of the study element into the suite of Vector Product Standards. This method allowed

the designers access to the substantial knowledge and experience base of the cooperative partners and maximized their input to the final standard.

In this second year of development the special studies continue with investigations into Digital Chart of the World product maintenance issues and Digital Chart of the World product organization.

Vector Product Standards

Now that the Vector Product Standards development cycle is complete, the final suite has been submitted as U.S. Military Standards. While the Vector Product Standards will enforce commonality among future Defense Mapping Agency vector data sets, it has been designed for generic application. The Vector Product Standards consists of the following sub-sections:

Tiling. This standard addresses the units of area coverage into which a geographic database is divided. In large data sets it is awkward to work with the entire database as one unit. This is solved by dividing the data into manageable areas. The design of the tile standard is determined by performance criteria, data maintenance issues, data manageability, most acceptable access time, CD-ROM medium characteristics, and size and configuration of the computing environment.

Indices. Indices provide a mechanism for quickly finding information stored on the CD-ROM. The Vector Product Standards provides format and structure for Spatial Query Index, Tile Index, Coverage Index, Gazetteer Index, and Thematic Query Index.

Digitizing Conventions. The Vector Product Standards digitizing conventions define how to collect linear data as a continuous feature; how polygon features should be closed; and how intentionally coincident features should be stored in separate layers when required. The digitizing conventions do not define procedures for the physical transfer of data from hardcopy to softcopy.

Digital Marginalia. The Vector Product Standards defines how information, normally stored in the margin of a paper map, should be included in the database. This includes such information as data currency, compilation date, last revision date, and intended use.

Vector Product Format. The Vector Product Format is the heart of the Vector Product Standards. This subsection defines the conceptual and physical data model. In the Vector Product Format features are created from four basic primitives: nodes, edges, faces, and text. These are physically implemented in binary primitive and feature tables. There are four types of

the conceptual and physical data model. In the Vector Product Format features are created from four basic primitives: nodes, edges, faces, and text. These are physically implemented in binary primitive and feature tables. There are four types of primitive tables: Node Tables, Edge Tables, Face Tables, and Text Tables. These tables contain topologic relationships and coordinate data. There are three types of feature tables: Point Feature Tables, Line Feature Tables, and Area Feature Tables. These tables contain a primitive record ID and attribute values.

The Vector Product Standards is designed to support varying levels of topology and varying degrees of integration. This relational approach will allow data to be separated into layers. When applications do not require querying of the relationships among data types, data can be stored in separate layers, allowing efficient storage and access. When such querying is required, the layers can be integrated, carrying full topological relationships in the process. After much consideration the geo-relational model was selected because 1) a majority of the reviewers of previous prototype products expressed a desire for thematic separate data, and many future products may be very thematic in nature; 2) the natural indexing of relational tables will allow data producers to distribute data without building special purpose indices to speed access for each user's separate needs; 3) the minimum target configuration is best supported by simple file structures; 4) special purpose weapon systems can more easily use the data.

Once the Vector Product Standards becomes a U.S. Military Standard all U.S. Department of Defense vector product users will be required to conform to the standard. Command, Service, and Agency contracts for map digitization will require adherence to this standard. This will create a pool of digital mapping and charting data generated to a known standard, allowing data exchange within the U.S. Department of Defense and Intelligence communities and enhancing a common goal of interoperability.

U.S. Military Specification.

Where the U.S. Military Specification is designed to be as generic as possible, a product's U.S. Military Specification is quite constrained. The U.S. Military Specification defines the Data Dictionary, the features and attributes included in the product, the feature coding schemes employed, the convention for portrayal of special feature relationships such as complex features, and all other product specific requirements. The Digital Chart of the World U.S. Military Specifications references the Vector Product Standards and defines the specific implementations of this standard in Digital Chart of the World production. It specifies the level of topology, integration, data collection criteria, and a specific sub-set of the tiling and indexing within the standard. It also implements other standards such as U.S. Military Standards for accuracy and ISO 9660 for CD-ROM.

THE DIGITAL CHART OF THE WORLD PRODUCT

Background

The secondary goal of this development effort is no less ambitious than the primary goal of standards development; this is the development of the Digital Chart of the World product itself. Once completed, the data base will contain 1.5 - 2.0 gigabytes of data stored on 8 - 10 CD-ROMS, providing a comprehensive 1:1,000,000 scale digital base map of the world. The Digital Chart of the World will be the largest spatial database designed specifically for exploitation on relatively inexpensive PC class computers. Special indices will be provided to guide the user through the database.

Several factors led to the decision to produce a product with global coverage. First, there has long been interest in the International mapping community for a global database. The International Cartographic Association and its Working Group developed the concept for a World Digital Database for the Environmental Sciences in 1984 (International Cartographic Association, 1989); and the International Geographical Union and others have documented the requirements for a global database over the years. Secondly, a global database fills the digital data needs of a wide variety of users. Anyone with regional, strategic, or global interests will have use for this type of data; it is applicable to the operational problem sets addressed by Intelligence agencies, Command, Control, Communication, and Intelligence groups, the mission planning community, theater and strategic commands, and environmental and global monitoring organizations.

Finally, development of a global database provides the opportunity to comprehensively address the issues of tiling and indexing by uniquely challenging design efforts in these areas. Tiling must not only divide the global data set into manageable units, but these units must be nested, because different users work with different amounts of area coverage. Likewise, users of large databases encounter difficulties in determining which data they need to extract, and how to extract it. Elaborate indices, directories, and application software must be provided to guide users through the data extraction session. Large databases covering smaller regional areas also face these same problems. The Digital Chart of the World is providing the means to test and prove out global design solutions that can be applied to regional digital data sets in the future.

Source

The 270 sheets in the 1:1,000,000 scale Operational Navigation Chart series comprise the primary source for the Digital Chart of the World. This series was selected because it is the largest

the World. This series was selected because it is the largest scale series that provides worldwide coverage; its scale allows expedient conversion to digital form; and Operational Navigation Charts are a product included in the Digital Production System. The series is also free from the restrictions governing the distribution of other products, allowing widespread dissemination of products derived from it. This primary source has been augmented by six charts from the 1:2,000,000 scale Jet Navigation Chart series in order to include Antarctica in the final product, making it truly a Digital Chart of the World. Conversion of hardcopy materials to digital form will provide the initial product; future editions and other Vector Product Standards compliant databases can be supplied by the Digital Production System.

The Operational Navigation Chart series provides standard topographic information consistent with basic 1:1,000,000 scale map products. This includes terrain elevation contours at 1,000 foot intervals; major transportation routes, including roads, single and multi-track railroads, and canals; populated places with city outlines; major drains and coastlines; and international boundaries

Approach

To create the digital database the chart production separates from the Operational Navigation Chart and Jet Navigation Chart series will be scanned and converted to vector form. The majority of separates (over 2000) will be scanned using a Scan-Graphics CF 1000 scanner. Three vectorization technologies are being employed to convert the raster data: the Optigraphics 3100 conversion system, Scan-Graphics Rave, and Hitachi CADCORE. Some separates will be hand digitized for efficiency. The vector data from these processors are then fed into the ARC/INFO system for creation of topological data structure, cartographic processing and editing, and quality control functions. Once the data have been converted into the Digital Chart of the World structure, the data will be transferred to the CD-ROM medium for distribution.

THE DIGITAL CHART OF THE WORLD

Database.

The database will be designed to support both geographic analysis functions and graphics display. Although the data are being collected from cartographic source, it will be treated as if it were geographic information. Linear features such as roads and railroads that were deleted in the original source due to cartographic symbology, precedence, or displacement protocols will be connected. Additional source material is being used to connect transportation routes through built-up areas. Contours will be stored as continuous lines, closed at the ends and connected

on the hypsographic data, and many other spatial operations. The database, used in conjunction with a symbol library and a large display device, will provide briefing and planning graphics. Each CD-ROM will be richly indexed to allow comparatively rapid access. The Digital Chart of the World will be available for distribution by early 1992.

Software

The Digital Chart of the World project is providing a comprehensive database for commercial Geographic Information Systems, as well as an application software package. The application software, along with its source code, allow simple database query. It is a user friendly interface employing a pop-down windows menu that will provide immediate access to the data.

The software provides a variety of methods for defining a study area. The user can retrieve data by delimiting an area on a coverage map of the world; by entering a latitude and longitude position; or by selecting a feature name from gazetteer query. Once an area has been defined the operator can then select the feature types to be extracted from the database. A query list will be generated to allow all features of interest to be extracted at one time; the menu will display only those feature types available in the area of interest. This allows the information to be pulled from the database in one pass through the CD-ROM, speeding access time. Features can be added to the query set incrementally; however, this would require many re-reads of the disk and would slow access considerably.

Once feature selection is complete the information can be displayed to the terminal screen. The operator will have the option to change the color and size of the symbols, to highlight select features, and to zoom using set increments. Once displayed, the software will provide cursor position read-out in latitude-longitude and simple distance measuring capabilities. The software also provides the capability to save selected data from the database, the query selection set, and a bitmap of the graphics display on hard disk. The bitmap will allow quick recall and re-display of information previously extracted from the CD-ROM. The user may also off-load a simple plot file.

Although the application software provided is not a geographic information systems, it allows the user to examine the database and provides some basic utilities. The accompanying source code is provided to allow geographic information systems developers and other computer literate individuals to bring the Digital Chart of the World database into their operating environment.

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